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THE NATURE OF THE THREAT OF OIL POLLUTION TO MARINE LIFE:

A RESUME OF THE CURRENT STATE OF KNOWLEDGE

BY:

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The potential for a major oil pollution incident in the arctic has increased dramatically over the past several years, leading Dunbar (1971) to suggest that oil pollution is now the most serious and immediate threat facing the arctic ecosystem. This is particularly true for the arctic marine ecosystem now that emphasis is rapidly shifting to offshore drilling in the coastal waters of the Beaufort Sea. The technological feasibility and potential hazards of such an undertaking are subjects of continuing debate and speculation. Particular concern has been expressed for climatological and ecological consequences of major submarine well blow-outs. The glaring inadequacy of our present understanding of both short and long-term effects of such accidents has been brought into sharp focus by this debate. Our ecological ignorance has made it difficult to realistically sustain or convincingly refute the many highly speculative predictions of widespread environmental disaster. As Dunbar (1971) so aptly puts it, "we have been caught in a state of scientific near nudity in the particular respect in which we now so urgently need protective covering; namely knowledge of what the proposed developments will do to the environment in precise terms, and knowledge of what should be done to conserve and protect."

This general uncertainty is unquestionably compounded by the fact that little reliable information is available about even basic ecology and physiology of the overwhelming majority of arctic marine species. This creates problems in the effective conduct and proper interpretation of experimental studies on interactions between crude oil and arctic organisms. Furthermore, it makes it especially difficult to assess the

applicability, in the arctic context, of generalizations about oil-ecosystem interactions derived from numerous studies conducted in temperate and tropical marine areas.

Even in temperate waters where intensive research has provided a solid information base, it is still impossible to predict, with any degree of confidence, the precise ecological effects of an anticipated oil spill. Even after a spill has occurred it has proven difficult to assess the overall environmental impact. Given the dearth of information about arctic marine ecosystems, any attempt at detailed impact prediction at present can only be considered an exercise in futility.

Ecological concern has thus far been centred upon those components of the ecosystem that are of direct present or potential economic importance to northern residents, particularly marine mammals and water fowl. Although one should not underestimate the importance of gaining as complete an understanding as possible of direct effects of oil on these economically important animals, it would be particularly short-sighted and potentially rather dangerous, to confine attention to just these species. They do not and cannot, exist in a vacuum, but are part of a complex ecological web characterized by a multitude of vital interdependencies. Thus far little attention has been paid to those "low profile" organisms of little direct economic consequence that, nevertheless, form a critical part of the ecological web upon which higher forms are dependent.

It is generally conceded that recovery from a severe ecological disturbance, such as a major oil spill, would be a lengthy process in the Arctic. This is a consequence of the slow growth, extended life



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cycles and longer reproductive periodicity of Arctic animals (Chia, 1970) as well as of the slow dispersion and degradation of oil at low temperatures (Glaeser, 1971). However, it is still not clear just how susceptible various components of the Arctic marine ecosystem are to damage by oil pollution. In view of the great complexity of potential interactions between oil and animal communities it would be manifestly impossible in a study of limited duration such as Beaufort Sea project to explore more than a few of the myriad aspects of the problem.

Unlike many other pollutants, crude oil is relatively insoluble in seawater. As a consequence, spilled oil does not spread uniformly through the environment but tends rather to concentrate in specific areas of the environment in a variety of forms. Marine organisms may thus encounter varying concentrations and forms of crude oil depending upon habitat and circumstance.

Interaction of animals with oil in any of the above forms may result in three distinct levels of effect. Threshold concentrations for each of these levels of effect differ considerably. Generally one can distinguish:

(1) Short-term lethal effects: in which the animals succumb rapidly. Usually oil concentrations in the high ppm or low ppt range are involved.

(2) Sublethal physiological effects: which do not result in rapid death of the organism but involve major modifications of a variety of physiological processes that may prove lethal in the long-term. Such effects generally become apparent at oil concentrations in the high ppb and low ppm range.

(3) Behavioral-integrative effects: which may not directly involve

major physiological disruptions but are reflected in inappropriate behavioral responses to either biotic or abiotic features of the natural habitat, either as a direct effect in response to the presence of oil, or as an indirect effect resulting from the masking or mimicking of natural chemical cues by specific components of the oil. Concentrations in the low ppb range may be sufficient to evoke responses.

In this study I have considered aspects of all three levels of effects but have emphasized sublethal and behavioral effects in the belief that these are more likely to have greater long-term, and more widespread ecological significance.

Problems in assessing oil impact in the Arctic

Oil pollution biology is a relatively new and active field as evidenced by the rapidly accumulating literature on the subject. Virtually all of the available information on the effects of crude oil on marine organisms and communities is derived from studies involving tropical and temperate ecosystems. The purpose of this review is not to provide an exhaustive survey of this growing literature, but rather to present a general conceptual framework upon which the meagre and fragmented information about oil effects in the arctic marine environment can be viewed to maximum advantage.

Few arctic marine oil spills have been studied in sufficient detail and for a long enough period to realistically assess the environmental impacts of such incidents. A complete absence of pre-spill baseline data has, in most instances, served to further compound the uncertainty. Impact prediction is rendered virtually impossible by the fact that

little reliable information is available at present about even the most basic ecology and physiology of the great majority of arctic marine species.

Any discussion of oil impact in the marine arctic must necessarily, therefore, rely heavily upon information accumulated in the many excellent follow-up studies of oil spills in temperate seas, and in laboratory studies upon temperate species. However, caution is required in using such information in an arctic context. Several features of the arctic marine ecosystem may have an important bearing upon the ecological consequences of an oil spill. Major crude oil spills in temperate waters (notably the Santa Barbara, California, and Torrey Canyon, off the southern coast of England, incidents) killed large numbers of birds and intertidal invertebrates, but were not as ecologically devastating to animals in the water column as anticipated. This should not make us overly complacent about the potential impact of comparable spills in the Arctic Ocean.

Factors influencing oil impact upon marine systems

The interacting variables

Studies on the impact of petroleum pollution upon marine ecosystems often yield conflicting or inconclusive results that make it very difficult to establish general principles. That this is so, is largely due to the very complex nature of the pollutant, both in its chemical and physical characteristics, and to the diverse physiological responses of different types of organisms to various components of the oil. Much of the difficulty in predicting oil spill effects is attributable

to the fact that the ultimate fate of each spill is determined by several interacting variables each of which may play a lesser or greater role in influencing the impact upon the ecosystem (Straughan, 1972). Several of these factors are common to arctic and temperate oil spills, others have important arctic aspects while some have features that are particularly unique in the arctic context. For convenience I have separated them into physical and biological categories.

Physical factors:

1. Type of oil
2. Dose of oil
3. Manner of introduction into the environment
4. Physiography and hydrography of spill area
5. Season of spill
6. Weather conditions
7. Method of treatment

Biological factors:

8. Season of spill
9. Adaptation effects
10. Interaction effects
11. Nature of biota
12. Mode of interaction of oil with animals

It is interaction of all of these complex factors in the uniquely arctic marine environment that will determine the overall impact of any given oil spill. In some spills one or two of these factors may assume an overwhelming importance in determining the magnitude of the impact.

I would like to briefly discuss these factors from the point of view of oil spills in arctic waters.

1. Type of oil

The type of oil spilled in an accident clearly has a major bearing upon the magnitude of the resulting ecological impact. Petroleum pollutants generally fall into two very broad categories. Non-persistent pollutants include the lighter refined components such as gasoline, kerosene, diesel oil, etc., that have generally been found to evaporate rather quickly following a spill. Persistent pollutants such as crude oil, bunker fuel, etc. have a large bulk of heavy components that may remain in the environment for an indefinite period of time. In the absence of far northern refining facilities at present it is the latter type of pollutants that are the most serious threat to arctic ecosystems. It is generally assumed that the toxicity of refined products is greater than that of crude oil, however, Butler and Berkes (1972) after an extensive review of the literature suggest that the available data does not warrant such a conclusion. Shelton (1971), however, maintains that apart from the light refined components, petroleum products are not highly toxic. This would also appear to be the general conclusion to be drawn from the extensive series of studies that followed upon the Torrey Canyon incident in which crude oil was spilled (Smith, 1970). However, toxic effects of crude oils have been widely reported (see review by Butler and Berkes, 1972). Much of the confusion, no doubt, arises from the fact that different types of crude oil vary quite extensively in their toxic effects as Ottway (1971) has clearly shown for several species of intertidal organisms. Kuhnhold (1970) reports a similar

phenomenon with regard to crude oil toxicity to herring eggs. Up to the present there has been no indication of the relative toxicity to arctic marine organisms of northern crude oils.

2. Dose of oil

That the quantity of oil spilled in a given incident markedly influences environmental impact is so obvious that little comment is required.

3. Manner of introduction of oil into the environment

The fact that the oil will be released into the water from the sea floor under very high pressure, rather than released relatively passively onto the sea surface, is likely to have important consequences in regard to the distribution of oil in various parts of the environment.

4. Physiography and hydrography of spill area

Coastal configuration, current flows, tidal conditions and physical characteristics of the water column will all play a major role in determining the magnitude of the area of the marine ecosystem affected by a major spill.

5. Season of spill

That seasonal changes in certain physical parameters such as temperature or ice-cover may influence the impact of an oil spill is obvious. Not so obvious is the fact that the susceptibility of animals to certain pollutants may vary considerably with season as a consequence of changes in the physiological condition of the animal (Crapp, 1971). Nothing, however, is known about seasonal variations in the sensitivity of arctic animals to crude oil.

6. Weather conditions

Weather conditions at the time of a major spill, particularly such factors as wind speed and direction, will play an important role not only in determining the magnitude of the area affected but also, by influencing sea state, in determining the quantities of oil mixed in the water column.

7. Method of treatment

The manner in which spilled oil is treated during clean up attempts is an important feature in determining biological impact. This was one of the major lessons learned from the Torrey Canyon spill, where the use of dispersants appears to have caused more ecological damage than did the oil itself.

8. Adaptation and interacting effects

Adaptation and interacting effects may subtly modify the impact of oil pollution on a given marine population. Studies in temperate regions suggest that some species adapt to continued exposure to low levels of petroleum and thus exhibit greater tolerance to more massive doses (Kanter et al., 1971). On the other hand, prior or simultaneous exposure of the animals to other types of pollutants may serve to increase the animals susceptibility to petroleum. In view of the relatively unpolluted state of the Arctic Ocean, neither pre-adaptation nor interacting effects are likely to play significant roles in modifying responses to oil spills.

9. Nature of the biota

There is a marked difference in the ability of different types of animals to tolerate the presence of oil in their environment. Even

allowing for different types of oil and different preparative and experimental techniques one is, nevertheless, forced to the conclusion that certain species can thrive in incredibly high concentrations of oil while other species are killed or severely stressed by even a hint of petroleum in their environment. The precise reasons for this remarkable difference in tolerance are not at present known, largely due to the fact that we have no very clear idea of which components, and what mechanisms of toxicity, are responsible for irreversible damage to organisms exposed to a given crude oil.

Data on sensitivities of various species to oil pollution have been derived from two different sources; field observations following accidental or controlled oil spills and laboratory toxicity studies conducted under standardized environmental conditions. The former are usually difficult to interpret because of the lack of controls and the potential involvement of a wide range of uncontrollable environmental variables that may modify the overall effect of the oil.

On the basis of the available data it is difficult to draw hard and fast generalizations regarding the oil tolerance of various classes of invertebrates. Difficulties in making comparisons arise from the fact that differences in the tolerance of species are obscured by differences in the oils involved, differences in method of application of the oils, differences in the degree of weathering of the oil, in addition to differences in a variety of other environmental parameters.

11. Mode of interaction of oil with marine organisms

The manner in which spilled oil interacts with organisms is an important factor in the overall impact of an oil spill. Crude oil, unlike many other pollutants, by virtue of its relative insolubility in seawater, does not spread uniformly through the environment from its point of release. The dose of oil to which a given population of animals will be exposed varies considerably, and often unpredictably, in different parts of the marine ecosystem. The physical form, eventual fate and ecological effects of spilled crude oil will differ greatly depending upon whether the oil is deposited in the intertidal zone, dispersed in the water column, adsorbed onto bottom sediments or accumulated in pools under the ice.

Biological effects of crude oil

Blumer (1970) in reviewing some of the potential biological effects of oil pollution in marine systems suggested that adverse effects upon organisms can be conveniently grouped into the following general categories:

1. Direct kill of organisms by physical effects such as smothering, or being trapped by oil
2. Direct kill of organisms by contact toxicity, i.e. by components that have low solubility in seawater.
3. Direct kill of organisms by seawater soluble compounds.
4. Destruction of sensitive larvae and eggs.
5. Destruction of food sources.
6. Sublethal effects resulting in direct long-term mortality or in reduced tolerance to normal stresses.
7. Interference with subtle behavioral and integrative mechanisms of individuals, populations and communities.
8. Incorporation and possible concentration of carcinogens and other potentially toxic compounds in the food chain.

The greatest emphasis thus far has been placed upon short-term lethal effects of the types outlined in categories 1-4 above. Toxicity tests have usually involved either immersing the animals in whole oil for specific periods and then returning them to clean seawater for observations, or more realistically, exposing groups of animals to seawater dispersions or water soluble extracts of crude oil for specific time periods (usually 96 hours).

Recently there has been a growing awareness that short-term lethality is an overly gross criterion for assessing ecological effects of pollutants. Useful as 96-hour bioassays have been in investigating certain aspects of pollution impact, they can never be considered as more than crude first approximations. Increasingly, emphasis is shifting to a variety of subtle sublethal effects that impair the organisms' ability to function effectively. Prolongation of such impairment may in time lead to the reduction or elimination of populations in the affected area. The physiological effects are often difficult to detect and only recently has there been a general appreciation of the many insidious forms they may assume. Warner (1965) and others have suggested that pollution biologists should be more concerned with a "toxic response syndrome", a complex of diverse behavioral, physiological and biochemical parameters.

There is limited but convincing evidence that crude oil released into the environment not only disrupts normal physiological functions of individuals but may also interfere with complex behavioral patterns necessary for effective integration of the various components of an ecosystem. This may be a consequence of a direct response to the presence

of oil or an indirect effect resulting from the masking or mimicking of natural chemical cues by certain soluble components of the oil. Kittredge (1973) has pointed out that effects of the latter type could impair the organisms ability to locate food, a suitable niche or sexual partners. Before further advances can be made in this area by pollution biologists it will be necessary to have much more comprehensive information on the utilization of natural chemical cues by marine organisms.

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